Progress Report - May 2000

Laguna Madre Sediment Model Simulations for Use in the Seagrass Productivity Model

Summary

The hydrodynamic and sediment transport model of Laguna Madre, Texas, was used to perform annual simulations of sediment resuspension with and without dredged material disposal. Output was extracted from the model at certain locations and used to drive the seagrass productivity model (SPM) of the Laguna developed by the University of Texas and Texas A&M seagrass modeling team. The purpose of the model simulations was to provide realistic suspended sediment time-series, especially within the seagrass areas where the SPM stations were located. In addition, the model results were processed and displayed here to gage water column and seagrass light-availability impacts in the proximity of the six placement areas included in the disposal scenario.

Introduction

Laguna Madre contains important seagrass habitat which support endangered species. A numerical hydrodynamic and sediment model of Laguna Madre was developed at the request of U.S. Army Engineer District, Galveston, to address concerns related to dredged material placement, resuspension, dispersion, and impacts to seagrass. This modeling study was part of a relate series of studies on possible dredging impacts to seagrass.

Wind-waves are the most important factor for sediment resuspension in Laguna Madre. Wind speeds are high, while tidal currents are relatively weak. There are feedbacks between seagrass, resuspension, and light availablity which have been found to operate positively or negatively in other systems. The technical issue is whether or not resuspended dredged material limits the growth, survival, and re-establishment of seagrass by limiting the availability of light to the macrophtes. Seagrass limits resuspension, and suspended sediment concentrations are generally low in seagrass areas.

Model Description

The finite-element model RMA10-WES was used for the basis for a model of the Laguna Madre. Special features were added to the model for application to Laguna Madre to account for: (1) spatially-varying atmospheric friction coefficients that improved atmospheric shear stress computation in very shallow water depths and in seagrass areas which comprise a large fraction of this system, (2) the partitioning of atmospheric shear stress to account for wave dissipation by white-capping, and (3) the bed-sheltering effects of seagrass.

The model solved mass and momentum conservation equations over a two-dimensional horizontal finite-element mesh including Lower Laguna Madre, Upper Laguna Madre, and the GIWW. The tidal boundaries were located outside the system: north of the J.K. Kennedy Causeway in Corpus Christi Bay, Port Mansfield Inlet, and Brazos Santiago Inlet. Freshwater inflow was included at Arroyo Colorado at the average of 14.2 cu m/sec. Evaporation was included in model calculations to represent the average annual deficit between rainfall and evaporation.

The model mesh describing the geometry of the system consisted of about 20,000 nodes. These nodes are shown as dots in Figures 1-3. The mesh had highest resolution generally near the Lower Laguna Madre navigation channel and around disposal areas, and near the mouth of Baffin Bay in Upper Laguna Madre. Element size varied. For example, in the GIWW they were 125 ft wide, while elements at the other extreme had sides thousands of feet long. Model depths were extracted and interpolated from a 1995 whole-bay survey performed by John Chance & Associates under contract to the U.S. Army Engineer District, Galveston. The survey provided excellent spatial coverage and extended across the "shore" to provided data up to about +2 ft mllw. The bathymetry of the Laguna Madre is shown in Figures 1-3. In these and other figures, 5000-m grid lines and 1000-m-spaced grid points are shown, as well as a brown line at the outside edge of the mesh.

Winds for the model simulations were developed from data obtained from the CBI-TCOON system. Wind data from Port Mansfield, Arroyo Colorado, the Corpus Christi Naval Air Station, and South Bird Island were downloaded, compiled together, and smoothed with a three-hour filter. Winds from South Padre Island were not available for this period. Tidal elevations required by the model as boundary conditions were developed from Bob Hall Pier and Packery Channel station data obtained from the CBI-TCOON system. These tide data were also smoothed with a three-hour low-pass filter.

Elemental material types were assigned based on the union of mean bed sediment phi-unit grain-size and bed sediment cover (bare, three seagrass species, or reef). Data from 1986 and 1989 Texas Bureau of Economic Geology reports were used for grain size and sediment cover, while more recent data from the seagrass modeling effort was used to define the spatial extent and dominant seagrass species. Approximately 55 element material types were employed. Atmospheric friction coefficients, bed friction coefficients, and bed-sheltering coefficients were assigned by elemental material types.

Four grain classes were specified in the sediment model to cover clay, two silts and fine-sand sized material. The class size-intervals were logarithmically spaced. Classes were coupled during erosion and deposition to account for cohesion and the sorting characteristics of fine sediments. A three-layer bed structure was utilized.

Model Adjustment

Hydrodynamic model verification was previously performed using two data sets: a June 1991 data set that emphasized Upper Laguna Madre, and a June 1997 data set that emphasized Lower Laguna Madre. Both data sets were collected by the Texas Water Development Board. Measured tidal discharges, current velocities, and water levels were compared to the model. The model was operated with freshwater inflow at Arroyo Colorado, wind stress, evaporation, and tidal head boundaries. Seagrass areas were identified in the model by species and increased frictional coefficients applied in those areas, as described earlier. The model was also compared to CBI-measured currents, and to tidal amplitudes developed from the pressure measurements.

Previously, the sediment model was verified for the period September 1994 through August 1995 using CBI-measured TSS. Dredging and disposal occurred in early October of that year.
Sediment transport characteristics were developed by laboratory erosion and settling experiments, and by model parameter optimization to observed suspended sediment concentrations. CBI-measured TSM concentrations at three locations near the PA 233 disposal area in Lower Laguna Madre September 1994 through August 1995 (FIX 1-3). Samples were collected at 0600 and 1800 hours daily by automatic sampler. CBI also collected TSM data in 1995-1996 in the middle of the seagrass area north from Port Isabel (LLM2a).

The model adjustment for this scenario included seven stations monitored by the Texas State Natural Resources Conservation Commission (TNRCC). The TNRCC station numbers were in the range of 13443 and 13449. The first two digits were dropped here. These stations are located close to the GIWW as shown in Figures 1-3 and arranged North to South in the table to follow. Also included in the table are CBI stations in the bare area near PA 233 (FIX) and in seagrass (LLM2a). The GIWW channel and channel side-slopes are described in the model using four material types. Model adjustment was therefore limited to global sediment parameters. Values of total suspended material (TSM) at 15, 50, and 85 percentile levels were determined from results and were as follows:

	TSM, mg/l					
	Field			Model		
Station	15 %	50 %	85 %	15 %	50 %	85 %
TNR-443	8	26	56	6	29	99
TNR-445	11	25	51	8	28	60
TNR-444	15	34	81	21	47	89
TNR-449	12	24	60	24	60	116

TNR-448	16	27	54	11	24	51
TNR-447	15	30	60	5	25	87
TNR-446	13	30	61	10	21	45
CBI-FIX[1]	65	150	253	51	91	144
CBI-LLM2a[2]	11	15	28	13	18	31

Scenario Description

A worst-case dredged material placement scenario was simulated with simultaneous disposal at three sites in Upper Laguna Madre and three sites in Lower Laguna Madre. The placement characteristics were as follows:

COE Placement Area	Area, m^2	Disposal volume, cyds	Disposal Rate, dry-kg/m^2	Total Disposal, dry-kg	Approx. Placement Thickness, m
187	4.5e5	87,250	85	4.38e7	0.08
197	5.2e5	655,000	414	32.96e7	0.50
202	7.8e5	512,000	330	25.74e7	0.39
211	10.3e5	680,000	330	34.09e7	0.36
221	12.8e5	844,000	330	42.32e7	0.34
233	23.0e5	380,000	83	19.0e7	0.11

The total placed volume was 3.158 million cubic yards (cyds), about 50 percent greater than the average annual dredging in Laguna Madre. A solids content of the disposed material was assumed to be the same

[1] Model data for disposal scenario.

[2] Model data for non-disposal scenario.

as the channel material, about 660 dry-kg/m^3. The placement in the model consisted of two parts. Seventy percent of the total material at each site was placed in the bed and the remaining thirty percent was initially suspended in the water column within the placement areas as a plume. The grain size distribution of the component parts and total disposed material used by the model were were based on analyses on channel sediments as follows:

Placement Fraction	Percent < 4 μm	Percent 4-16 μm	Percent 16-64 μm	Percent > 64 μm
Bed Deposit	22	29	29	21
Suspended Plume	76	17	7	0
Total	38	25	22	15

The placement was simulated to occur on 1 April 1995. The bed placement was accomplished in 24 simulated hours in the model. The suspended plume was formed as a constant flux into the water column over 119 hours, or roughly 5 days starting 1 April 1995. The simulation continued until 1 September 1995 and then wrapped back to 1 September 1994 and continued until 1 April 1995 for a total simulation time of one year.

Tidal and wind-driven currents were calculated, combined with wind-wave shear stresses, and used to calculate sediment erosion, deposition, and transport for the simulation period of one year. Scenarios with and without dredged material placement were simulated.

Results

The percent of material resuspended from the placement areas was calculated at the end of the year-long simulation. Results were as follows:

COE Placement Area	Total Disposal, dry-kg	Percent Lost by Erosion and Transport
187	4.38e7	23.3
197	33.0e7	30.5
202	25.7e7	28.8
211	34.1e7	19.4
221	42.3e7	24.7
233	19.0e7	42.7

Total loss from the placement areas was 43.7e7 dry-kg or about 28 percent of the overall disposed mass. This loss converts to a channel volume of about 8.71e5 cyds.

Model channel shoaling along the length of the GIWW was 4.0e6 cyds without disposal and 4.23e6 cyds with disposal.

Water Column Impacts

Model results were used to calculate the increase in total suspended sediment resulting from the placement of the dredged material and its subsequent resuspension from the placement areas. Disposal effects were estimated by averaging the period of the plume release. During this period, currents carried the plume outside the limits of the placement areas in some cases. These differences in total suspended material (TSM) are shown for the six disposal areas in Figures 4-9. The surrounding mesh resolution and the boundaries of the placement areas are also shown in Figures 4-9. In these and other figures, 5000-m grid lines and 1000-m-spaced grid points are shown.

The average post-placement TSM differences for the remainding 597 hours of April 1995 after the placement are shown in Figures 10-17.TSM difference plots for May through August are shown in Figures 18-33. If the plots for specific placement areas are missing then TSM differences were less than 8 mg/l. Plots of TSM differences for the six placement areas for the remainder of the year are shown in Figures 34-57. Missing plots had less than 4 mg/l difference in this set.

Light Availability Effects

The SPM model team determined a relationship between total suspended sediment (TSS) and the diffuse attenuation coefficient K_d for photo-active radiation:

$$TSS = 0.15937\,K_d^2 + 13.9K_d - 4.569$$

Seagrass require about 20 percent of the surface irradiance I_o to survive long-term. The irradiance reaching the seagrass depends on the water depth h and K_d:

$$I = I_o \exp(-K_d h)$$

where I is the irradiance reaching the bed. Combining these expressions for use in the model post-processing system yielded:

$$\ln\left(\frac{I}{I_o}\right) = ((196.1226 + 637.48\,TSS)^{0.5} - 13.9) \times h \,/\, 0.31874$$

where the TSS is the monthly average in kg/m^3 and h is a negative value measured downward from the water surface in m. Note that the TSS value used for this calculation was the mean for the respective month, and, since the distribution of TSS is quasi-lognormal, the means are higher than the medians and skewed toward the upper end of the distributions. The conversion of $ln(I/I_o)$ to percentiles reaching the bed is as follows:

Percentile of Irradiance Reaching the Bed (I/I_o x 100)	$ln(I/I_o)$
50	-0.69
30	-1.204
20	-1.609

10	-2.303

Contours at the above percentiles are plotted for April and August for the disposal scenario in Figures 58-61.

As stated earlier, the critical value for seagrass survival is about 20 percent bottom irradiance. The 20-percent contours for disposal and non-disposal scenarios are shown in Figures 62-97. The disposal scenario contour lines are shown in blue and the non-disposal lines are shown in green. The blue line eclipses the green line so that if only a blue line shows in a figure there was no difference between the two. There was no divergence of lines in the vicinity of PA 187 so this area was not displayed. In these and other figures, 5000-m grid lines and 1000-m-spaced grid points are shown.